The CoWS Experiment:

Convective Weather Sources

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Outline

- Motivation
- CoWS Experiment Objectives

- Apparatus & Test Range
- Flight Scenarios & Participants
- Experimental Design & Protocol

- Results
- Discussion

- Next Steps

How will AWINs be used?

… with other sources of weather information?

… with respect to data limitations?

CAUTION

FIS information is to be used as a strategic planning tool for pilot decisions on avoiding inclement weather areas

…

The FIS information is intended for assistance in strategic flight planning purposes only

and lacks sufficient resolution and updating necessary for tactical maneuvering.

Bendix/King KMD 550/850 Pilot Guide

The CoWS Flight Experiment

How do **GA pilots** consider approaching **convective weather** situations with different **weather information sources**?

Sources *(independent variables)*

–Aural (ATC, HIWAS, Flight Watch)	~ *IFR*
–Out-the-window visual scene + aural	~ *VFR*
–AWIN + aural	~ *new IFR*

Effects *(dependent variables)*

–Subjective workload, information sufficiency,

–Situation awareness & characterization

–Decision quality, individual differences,

–Subjective ratings and preferences for display ...

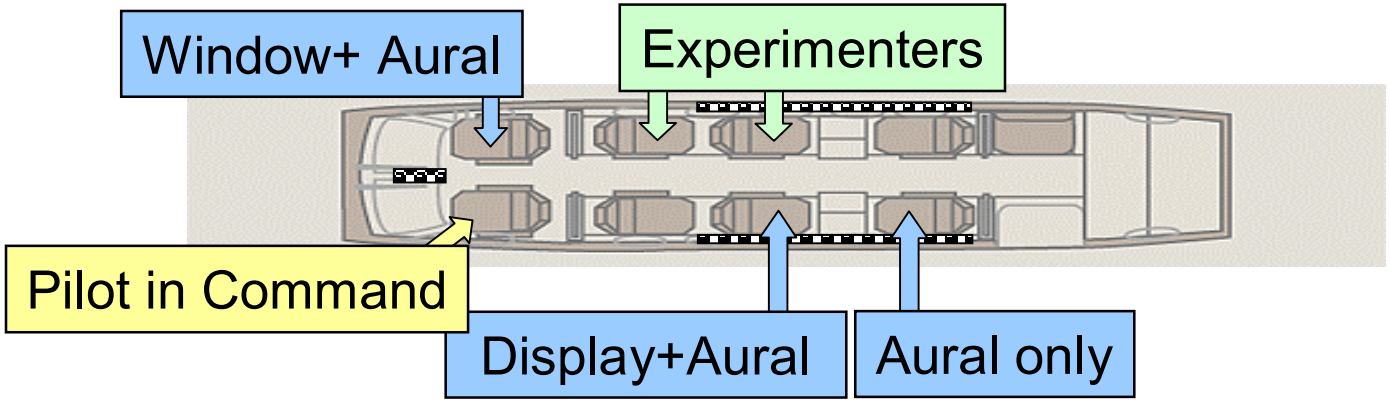
Participants & Design

Participants

- 12 GA pilots ~ 4 teams of 3 (levels of x-country hours)
- Instrument rating

For each subject

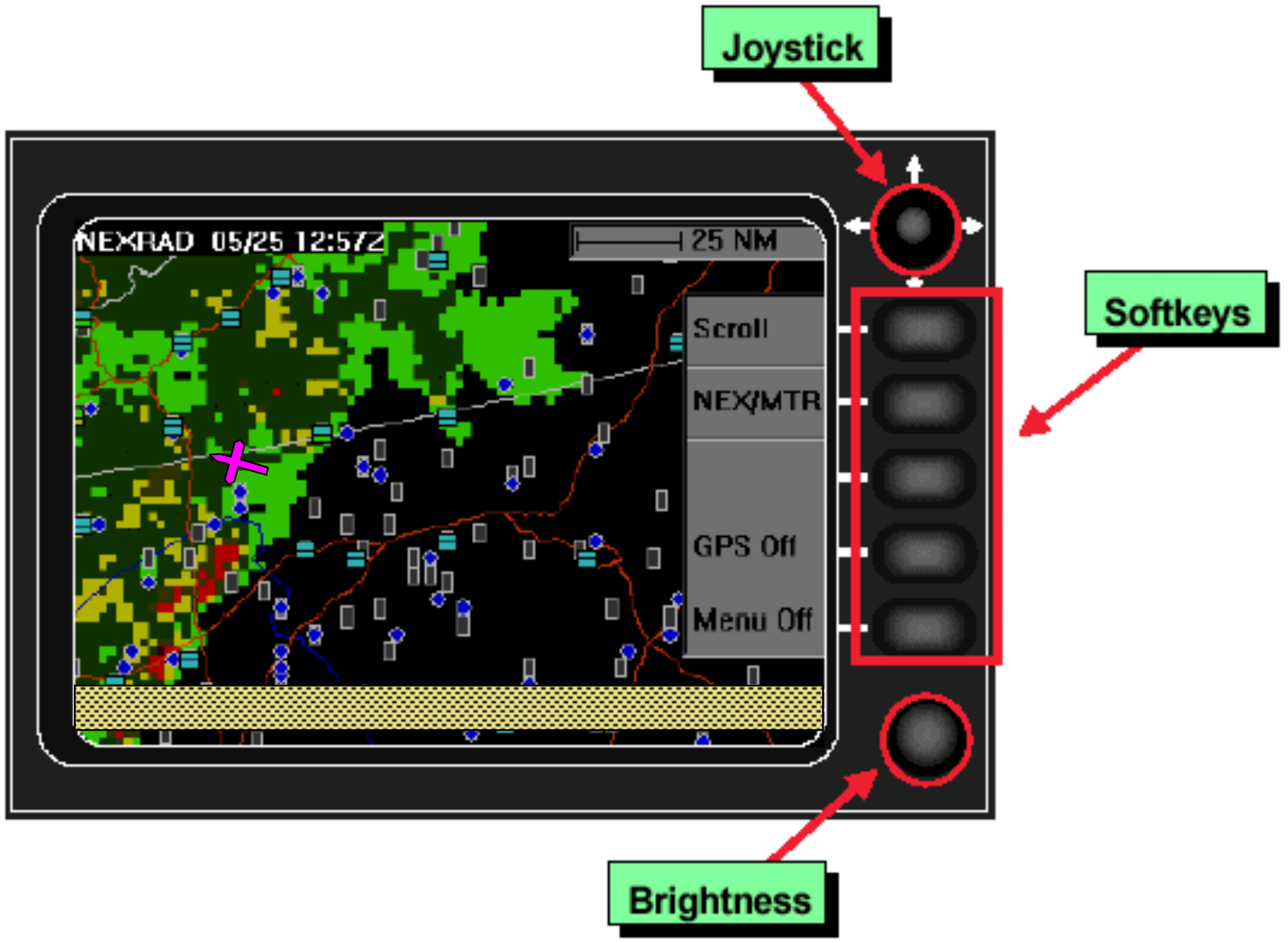
- Three flights (each weather source)
- 6 “proximity” observations of nearest cell
- 1 observation of “big picture” weather awareness



= Opaque covers for side windows & onboard radar

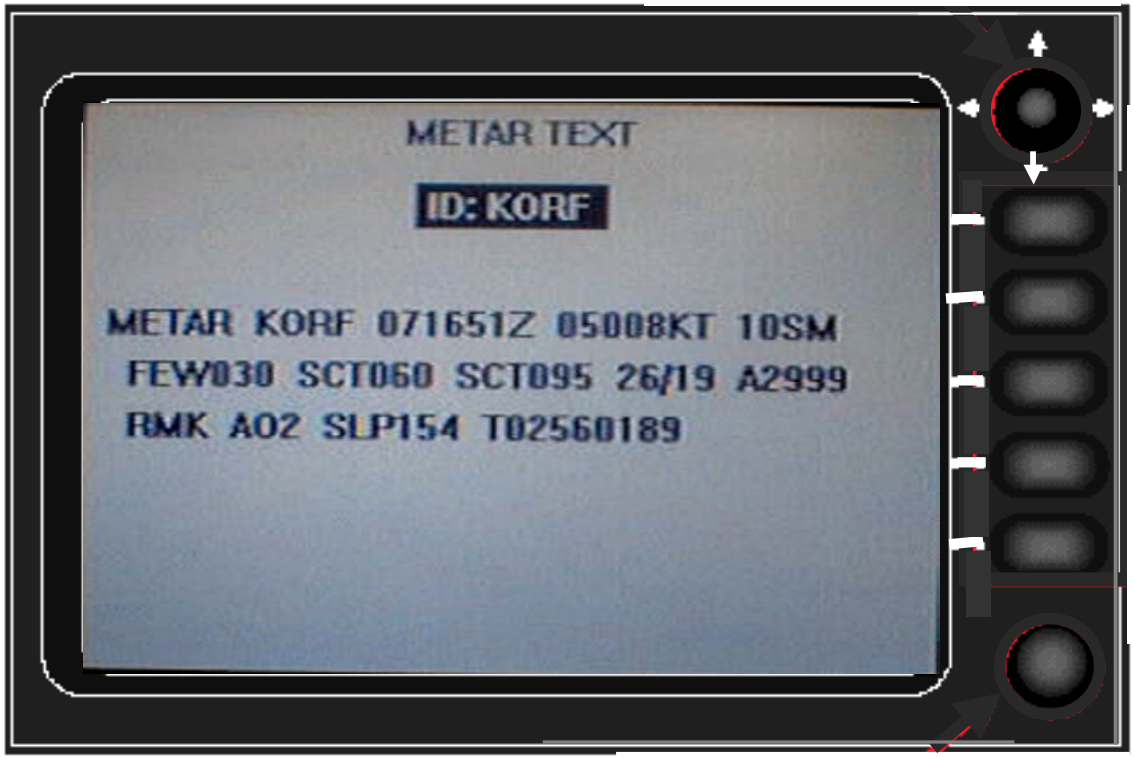
Prototype AWIN Display

NEXRAD
METARs
Aircraft position
Airports
Navaids
State lines
Water
Highways
Data outages



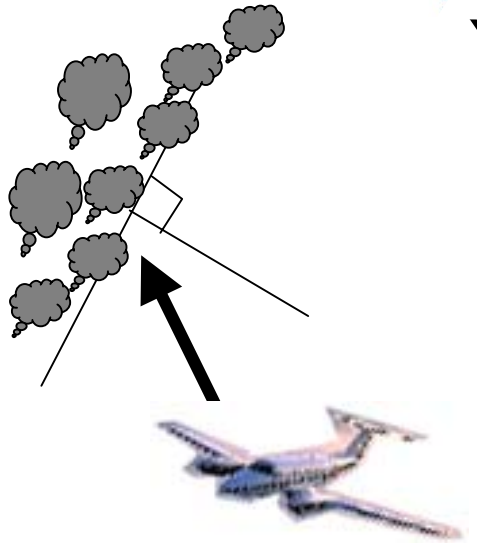
* "artist's conception" of aircraft & data outage symbols

METAR Text


METAR TEXT
ID: KORF
METAR KORF 071651Z 05008KT 10SM
FEW030 SCT060 SCT095 26/19 A2999
RMK AO2 SLP154 T02560189

Apparatus: B200 & AWIN Display

Scenarios



Flight Scenario

- Mission motivation
- Flying IFR, but in VMC
- NASA to destination, 1.5-2 hours
- Convective fronts ≥ moderate intensity

Presumed Aircraft ~ small single-engine

- Cruising Altitude = 14000', above haze layer
- Cruising Speed ~ 170kts true airspeed
- No radar-equipped, deicing equipment, pressurization

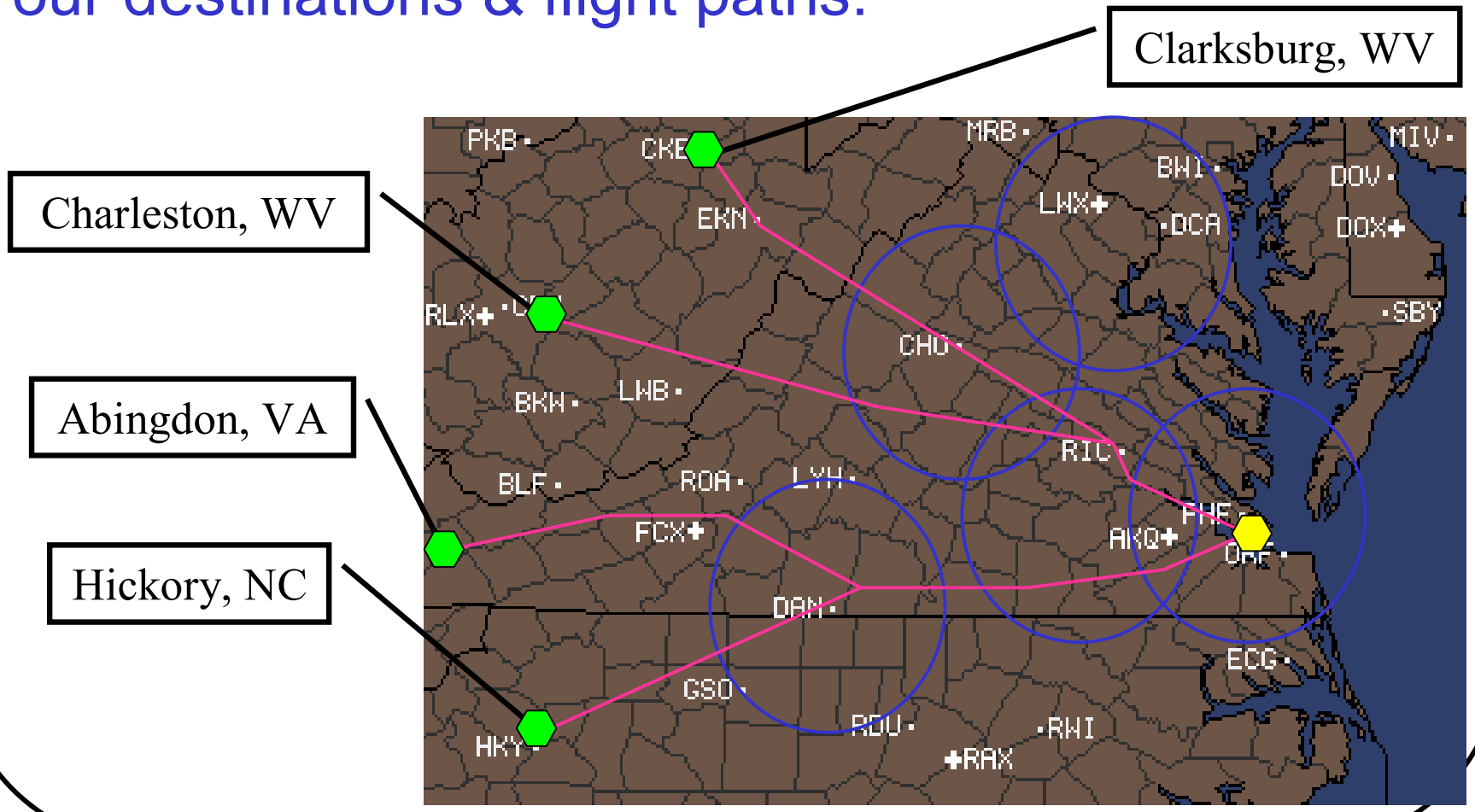
Role

- "Respond as if you are pilot-in-command"
- Other tasks: parameters, location plotting, calculations

Test Range & Flight Paths

Test range: 5 ground stations, 40nm radius

Four destinations & flight paths:



Experimental Protocol

Preflight

- Introduction to CoWS, assignment to conditions
- Mission, route, and regional information briefing
- Weather briefing
  - » *DUATS text & graphics, audiotaped FSS briefing (twice)*
  - » *Review & Preflight SA questionnaire*
- Intervening tasks
  - » *AWIN training*
  - » *Personality, risk, weather knowledge tests*

Flight

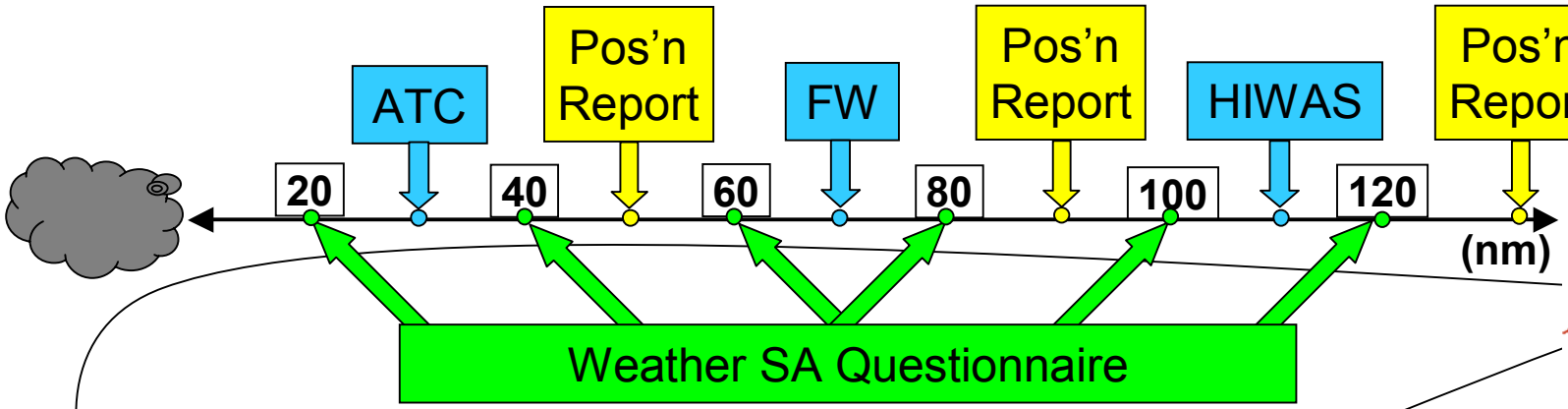
- Outbound phase
- Inbound phase

Debriefing

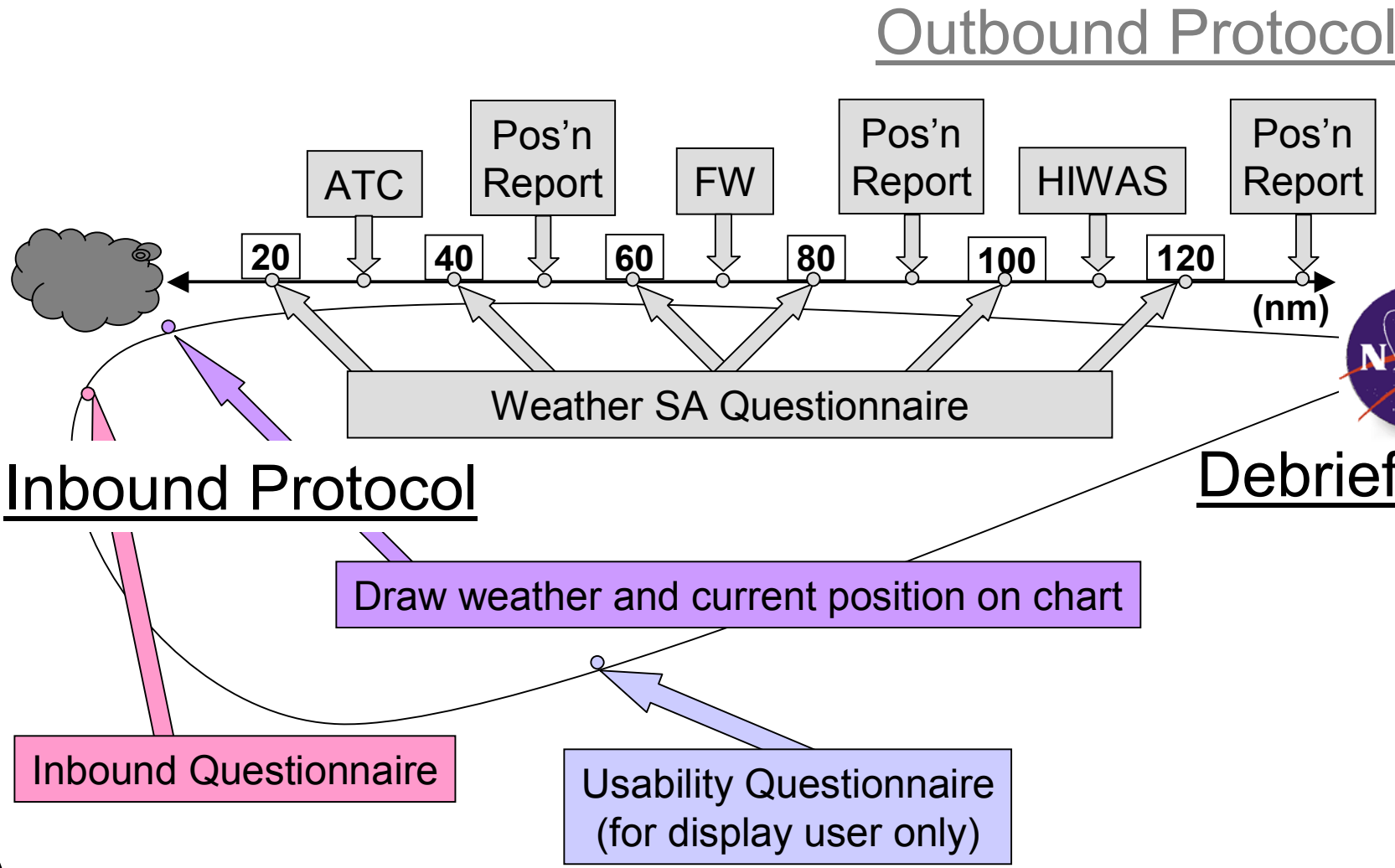
- Individual flights
- Team's last flight

In-flight Protocol

Outbound Protocol



In-flight Protocol



Outline of Analyses

Situation Awareness Assessments

- Cell detection accuracy* *(moderate or greater intensity)*
- Cell location estimation accuracy* *(bearing & range)*
- "Big Picture" SA accuracy* *(analysis of IFR chart drawings)*

Subjective Data

- SA Confidence*
- Perceived Information Sufficiency*
- Subjective Workload Ratings*

Subject Assessments of AWIN Display

- General impressions
- Presentation Elements & Weather Information Presentation
- Using this AWIN System: SA, Decisions

Design Intent vs. Usage

** (incomplete data sets)*

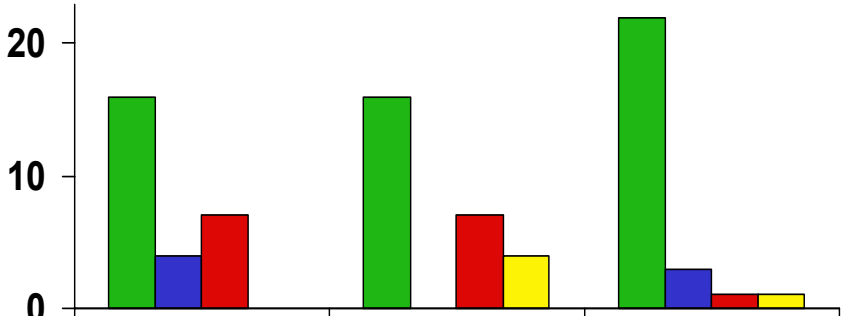
Cell Detection Accuracy

Detection Categories

- "Hit" *(cell present, and detected by subject)*
- "Correct Reject (CR)" *(cell not present & not detected)*
- "Miss" *(cell present and not detected)*
- "False Alarm (FA)" *(cell not present but detected)*

of 27 Samples, 23 had cells

- Display ~ 96% Hit rate
- Window~ 66% Hit rate
- Aural ~ 66% Hit rate

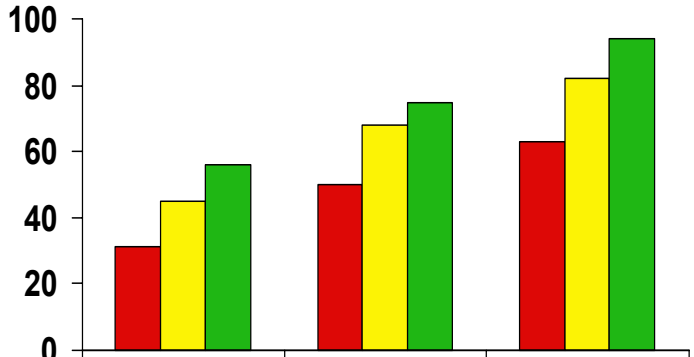


	Aural	Window	Display
Hit	16	16	22
CR	4	0	3
Miss	7	7	1
FA	0	4	1

Bearing & Range Estimates

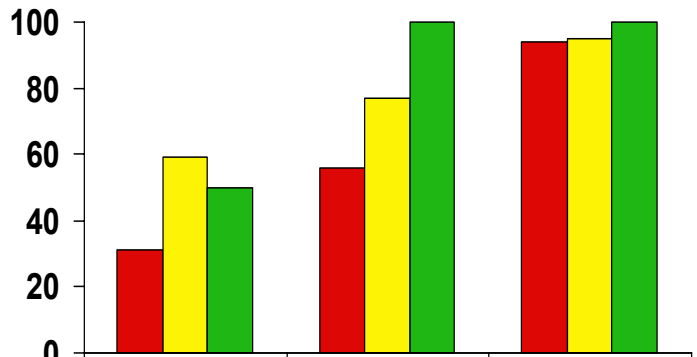
For Hits, percent accuracy of:

Bearing estimates



	w/in 25 deg	w/in 45 deg	w/in 90 deg
Aural	31	50	63
Display	45	68	82
Window	56	75	94

Range estimates



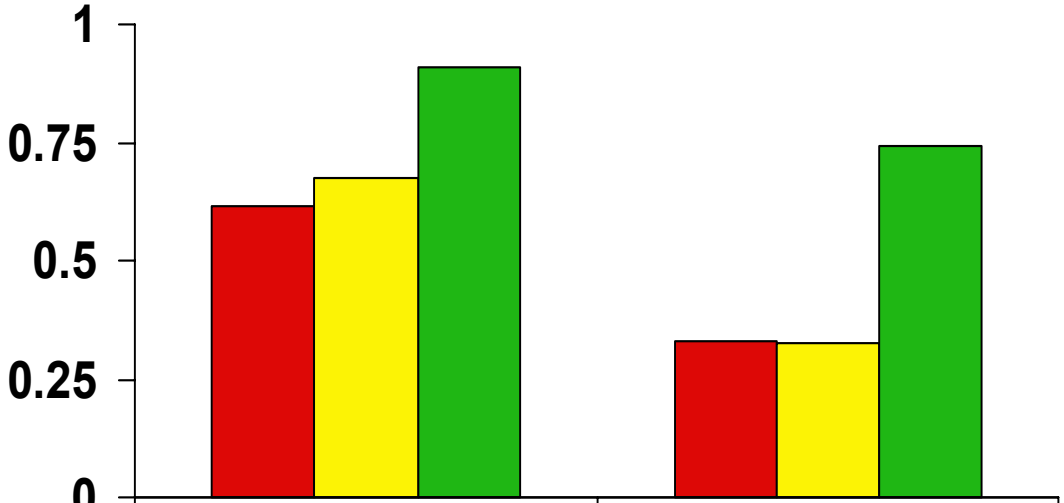
	w/in 25 nm	w/in 50 nm	w/in 100 nm
Aural	31	56	94
Display	59	77	95
Window	50	100	100

Ability to estimate bearing and range:

- Window > Display > Aural

“Big Picture Weather SA”

- SA with AWIN >> either Window or Aural
- Same relative rankings with and without CR’s



	SA Score (w/ CR's)	SA Score (no CR's)
Aural	0.615	0.329
Window	0.673	0.327
Display	0.91	0.743

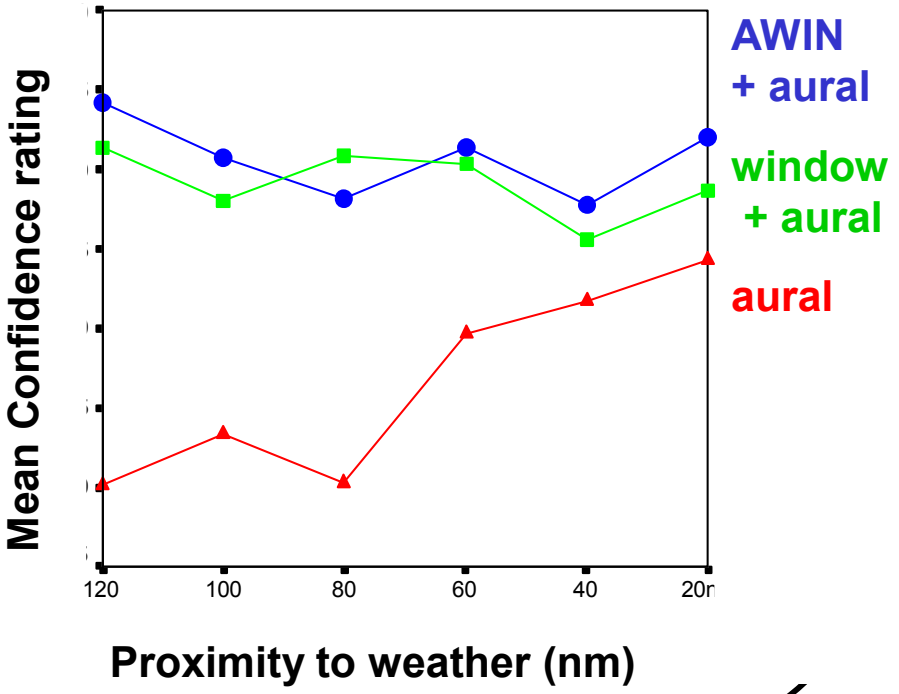
Subjective Confidence in SA

Summary of ANOVA

- Cue set ~ Highly significant ($p<.0001$)
- Proximity to weather ~ Not significant ($p=.691$)
- Cue set X Proximity ~ Not significant ($p=.275$)

Pair-wise comparisons (LSD)

- Aural *v.* Window ($p<.0001$)
- Aural *v.* Display ($p<.0001$)
- Window *v.*Display($p = .491$)



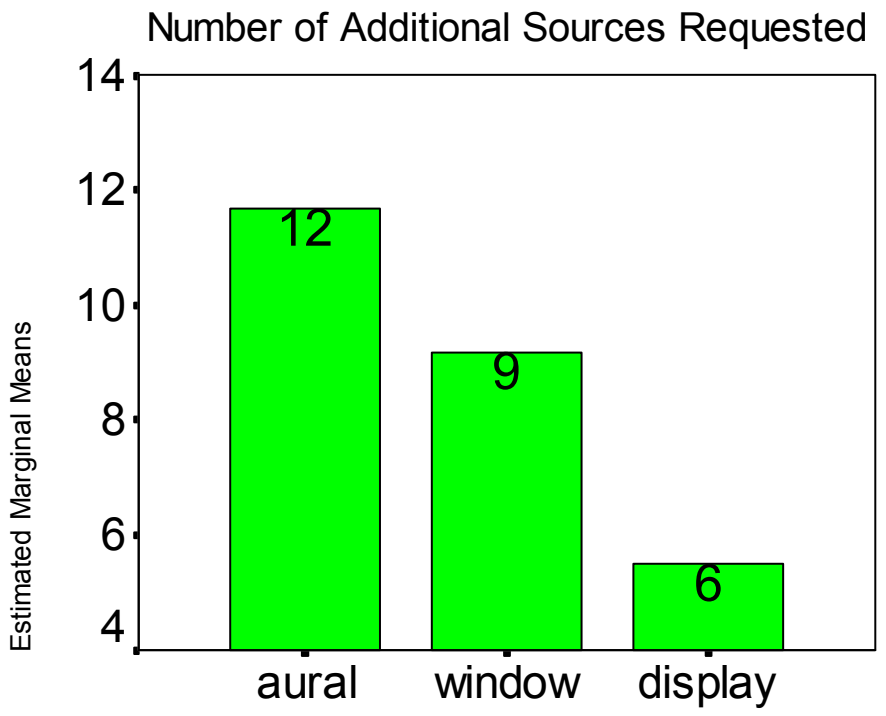
Perceived Information Sufficiency

Summary of ANOVA

- Cue set significant ~ Significant (*p<.061*)

Pair-wise comparisons (LSD)

- Aural *v.* Display *(p=.009)*
- Window *v.* Display *(p=.09)*
- Aural *v.* Window *(p=.24)*



Subjective Workload - NASA-TLX

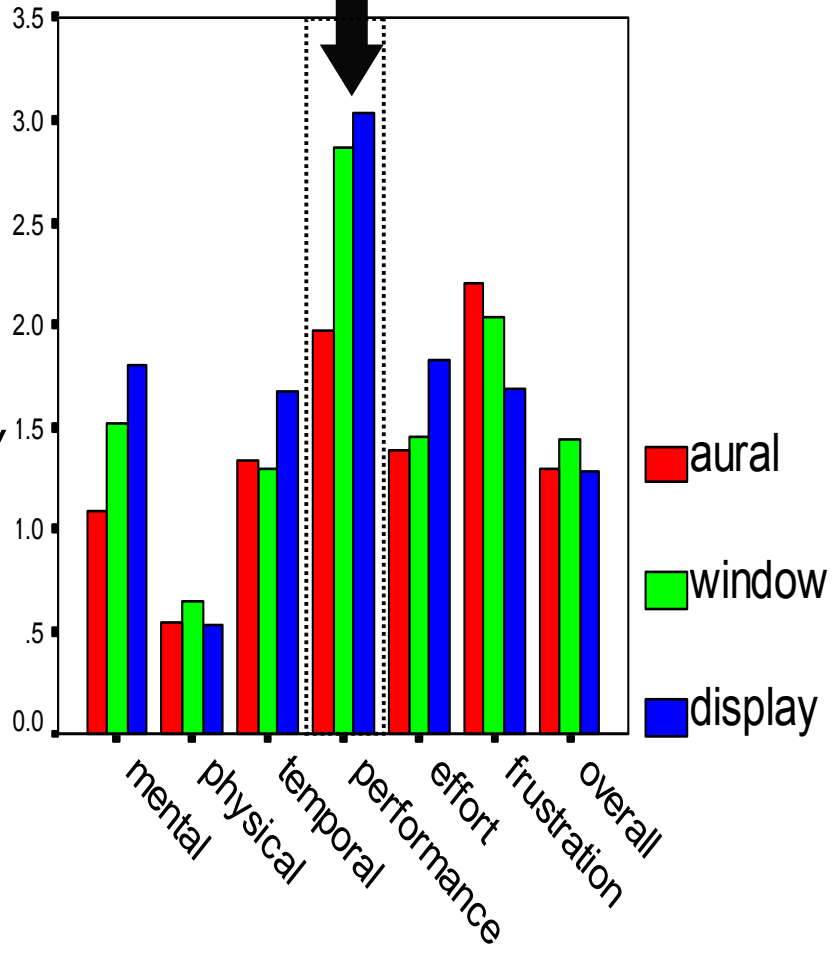
Summary of ANOVAs

- Peformance Rating
  - » *Cues set ~ Significant* ***(p<.09)***
  - » *Subjects ~ Significant* ***(p<.03)***
- Physical Rating
  - » *Subjects ~ Significant* ***(p<.02)***

Pair-wise cue comparisons

- Performance ~ *not significant*
  - » *Trend: Aural > Display, Window*

- *Subjects did report that workload was similar to that when actually flying.*



Participant Assessments

("Very" (>75% scale, a=0.05), "Fairly/Marginally" (>50% scale, a=0.05))

Initial comments reflect appreciation of utility. Usability issues identified later.

- Marginally more "Satisfying" than "Frustrating"
- Very much more "Easy" than "Difficult" to interact with
- Fairly easy to learn the system
- Fairly quick to learn the system
- Very easy to get started
- System very encouraging of exploration of its features

Presentation Features

Display resolution and clarity

- 320 x 240 pixels: "adequate," 3 desired higher resolution
- Text labels difficult to read, especially with bifocals
- Aircraft symbol distorted when not in cardinal direction

Contextual Features

- Airports: all 12 used, but not particularly helpful
- NAVAIDS: 8 used, only marginally helpful
- Problems: only 1 identifier at a time, odd NAVAIDS
  - *Insufficient to support positional SA*

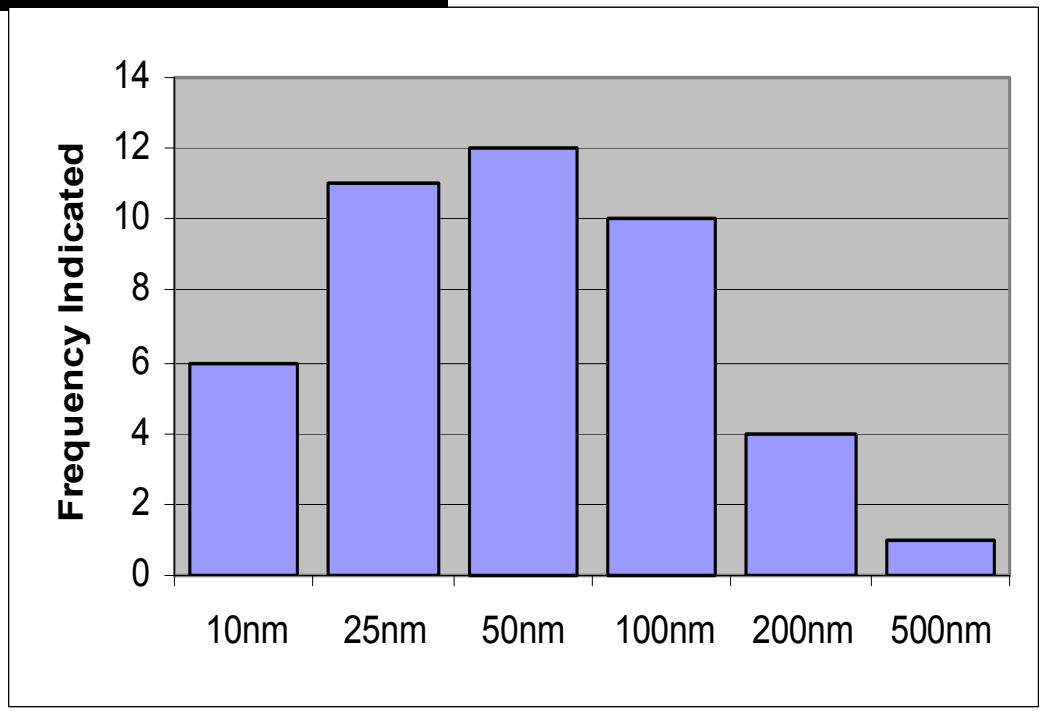
Airplane Symbol / GPS Modes

- Airplane symbol is very helpful
- Most switched modes (10/12)
- All but 1 prefer GPS-Free

Map Scales

Scale Usage

- 50nm most preferred
- largest with all context



Scale Legend

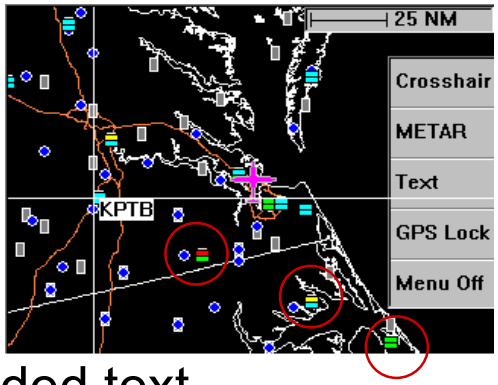
- "Unit bar" indicator requires user to measure
- Prefer: range rings (4), cursor-based measurement (1)

Surface Observation Information

Ceiling (marginal VFR)
Visibility (VFR)

Symbology

- Not particularly useful for these scenarios (convective, enroute)
- Color-coded ceiling & visibility fairly helpful
  - » *but difficult to see with NEXRAD present*
- Deselected often to reduce screen clutter



Text

- Content very helpful
- Format very easy to read, able to translate coded text
- Text obscures graphical weather information
- Awkward, long process (5-steps worst case) to access

Age

- Age only available in text; many relied on symbols (5/12)
- Rated data age fairly apparent, but older than acceptable (9/12)
- Most (8/11) were less than 52% confident of “oldest METAR”

Weather Radar Information

Weather Radar (NEXRAD) Presentation

- NEXRAD information and color-coding very helpful
- Radar return resolution too coarse at small scales (5/10) and insufficiently precise to judge intensity gradient

Age of NEXRAD Data

- On average, 90% rating on *"how apparent is the age?"*
- Half didn't recall using age of the NEXRAD information (6/12)
- Most < 50% certain about oldest NEXRAD (7/12), 3 were 0%
- On average, age of NEXRAD rated less than fairly acceptable

Considered fairly reliable on average

Situation Awareness

Level 1 SA – Location & Intensity of Weather

- Provides great improvement over aural information
- Useful contextual features aid position interpretation
- Update rate and data outages diminish confidence in wx position
- METAR symbols used to identify regions of IFR on surface

Level 2 SA - Relevance to Pilot, Aircraft, Mission

- Estimating distances from airplane
  - » *Unit bar is difficult to use*
- Estimating the relevance of the weather information
  - » *Age alerts*
  - » *Displaying older data when new data is incomplete*
  - » *Need finer resolution NEXRAD at smaller map scales "too blocky"*

Level 3 SA – Projecting Weather & Mission Dynamics

- Need better method for getting predictive information (8/12)

Participant Recommendations

Additional Information

- Cloud tops
- Pilot Reports
- VFR/IFR/LIFR regions
- Turbulence
- Windshear
- Icing
- Terminal Area Forecasts

- Complete NAVAID/Airport database
- Destination icon
- Airways
- Course line
- Flight path
- Aircraft heading
- Range rings
- Distance calculation

Presentation Methods

- Vertical perspective (*profile view*)
- METARs: dedicated window or aural presentation
- Higher resolution NEXRAD & NEXRAD trend information:
  - » ***Animation, Direction & speed arrows, prognostication***
- Weather hazard alerts >>***Phenomena intensity & proximity***
- Presentation of weather information age & reliability

Using AWIN Displays

CAUTION

FIS information is to be used as a strategic planning tool for pilot decisions on avoiding inclement weather areas

The FIS information is intended for assistance in strategic flight planning purposes only

Bendix/King KMD 550/850 Pilot Guide

Subject comments

- *"(I) assumed it was real-time,"*
- *"Could thread the needle with it,"*
- *"Good enough to make a divert decision."*

Preliminary results

- More confidence in big picture SA
- Less likely to want additional weather information
- Best detection: more Hits, fewer Misses & False Alarms

Using data age information

- Age is apparent, but half didn't recall using NEXRAD age (6/12)
- Most were < 50% certain about oldest NEXRAD (7/12), 3 were 0%
- Only a few said delay makes precise information unreliable (3/12)

Design Intent vs. Use

Aeronautical Information Manual (7.1.10)

"not appropriate for use in tactical severe weather avoidance"
"supports strategic weather decision making"
"(not used) in lieu of an individual pre-flight weather & flight plan brief"

Minimum Aviation System Performance Standards (RTCA DO-267)

"FIS-B will be used for strategic/planning purposes."

Bendix-King KMD 550/850 Pilot Guide

CAUTION

FIS information is to be used as a strategic planning tool for pilot decisions on avoiding inclement weather areas

...

The FIS information is intended for assistance in strategic flight planning purposes only

...

lacks sufficient resolution and updating necessary for tactical maneuvering.

Using AWIN Displays

Define tactical & strategic use with respect to weather information

Strategic uses of AWIN

flight planning, identifying safe route, proactive, planning to avoid encountering hazards and need to respond tactically, obtaining big picture of weather, determining type of flying (IFR, VFR).

Tactical uses of AWIN

steering/ maneuvering to avoid weather hazards, threading around cells, exiting hazardous weather, responding in a reactive and immediate way to local weather.

Tactical/Strategic Questionnaire

Indicate the closest "time to encounter" in each situation that you would still be reacting "strategically"

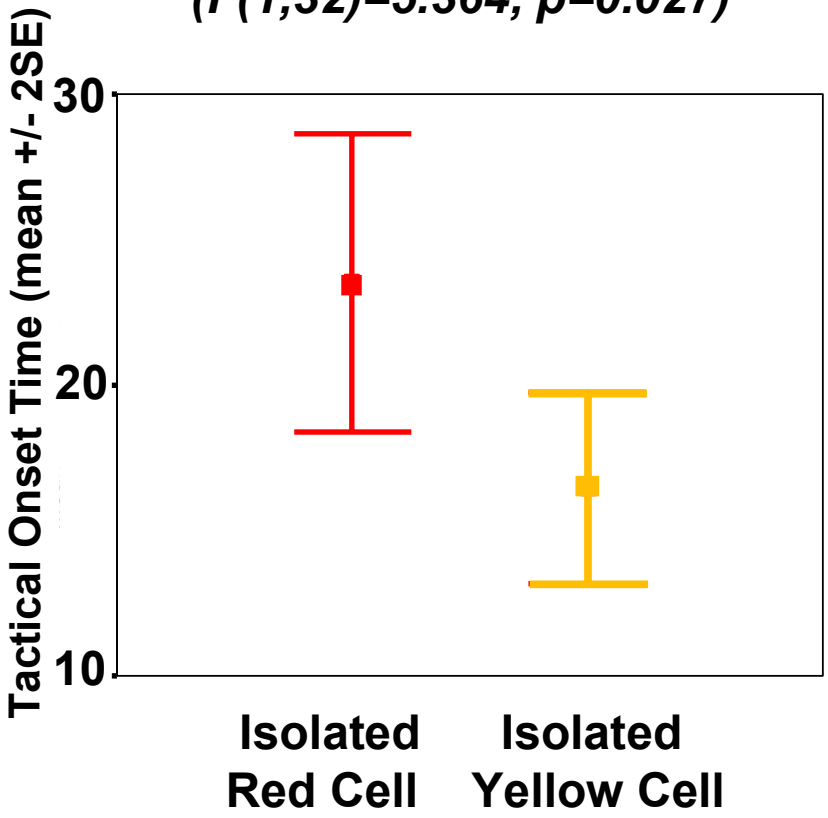
- **an isolated yellow cell along your route of flight.**
- **an isolated red cell along your route of flight.**
- **an area of severe thunderstorms perpendicular to and extending 5, 10, 15, 20, 30, 50 nm to either side of your route.**

Delineation by Time-to-Encounter

Tactical is further away for isolated

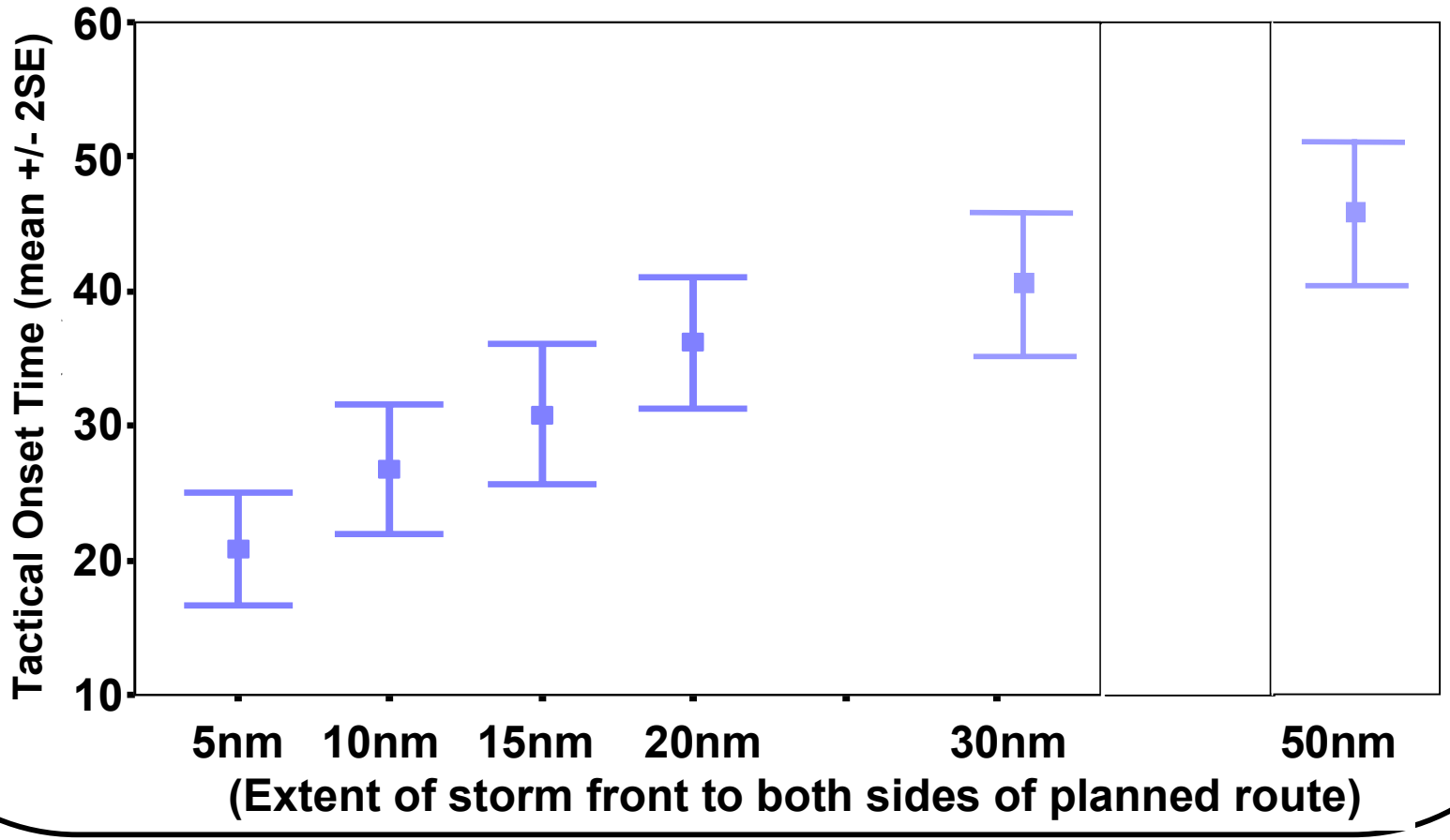
red (23.5 min) than yellow (16.5 min) cells

(F(1,32)=5.364, p=0.027)



Delineation by Time-to-Encounter

"Tactical" starts earlier for wider severe storms.



Inflight Questionnaire Probes

Inflight Questionnaire *(6 points, 8 min. apart, approaching weather)*

- Estimate the range and bearing to the nearest cell of moderate or greater intensity
- How would you characterize the current situation with respect to avoiding weather?

  Tactical----------Strategic
- Based on your "weather picture," proceeding along the intended route is

  Extremely Risky----------Entirely Safe
- How confident are you that your "weather picture" is complete and accurate?

  Not at all----------Extensively

Influences on In-Flight T/S Ratings

Candidate factors *(stepwise regression models)*

- cell distance (*nearest cell ≥ moderate intensity, +/-45^0 heading)*
- cell angular offset
- confidence in "weather picture" completeness/accuracy
- risk of proceeding along intended route
- subjects

Significant factors ***(standardized coefficients p<0.01; models p<0.001)***

- Aural only: less risk & larger offsets ⇒ strategic
- Window+Aural: less risk & larger distance ⇒ strategic
- AWIN+Aural: *risk level* & subject differences

Using AWIN Displays

What helps you deal strategically & tactically with weather?

Strategic Features

- ✓ Map scales => 100nm
- ✓ Integrate over Graphical METAR symbols for surface conditions
- ✓ Ability to get weather information beyond AWOS range
- ➢ Storm trend & predictive information

Tactical Features

- ✓ Cell position and intensity information
- ✓ Weather at alternates
- ✓ Proximity to aircraft (aircraft symbol)
- ➢ Distance to aircraft (range rings)
- ➢ Higher resolution NEXRAD (5/10 subjects said too coarse at 5nm scale)
- ➢ Direction of storm movement
- ➢ Action guidance (penetrate, circumnavigate, reverse course)

Summary of Results

SA Performance Assessment

- Best cell detection and overall weather SA
- Better cell bearing & range estimates than aural

Subjective Assessments

- As confident as with window view ~ *maybe too confident*
- Less likely to seek information from ground sources
- Perceived performance similar to window condition

Subjective Evaluation

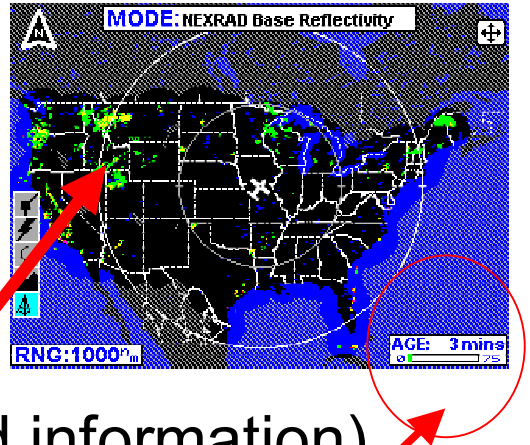
- Functionality embraced ~ Usability issues persist ...
- Design Guidance: features, controls, information, …
- Appropriate use?

➔Tendency & desire to use AWINs tactically

Implications

Operational Guidance

- Weather information sources are complementary
  - » *AWIN for strategic weather situation awareness*
  - » *Window view for tactical clearance and near weather avoidance*
  - » *Aural sources for corroboration and trend data*
- Defining appropriate, “strategic,” use in meaningful terms



Design Guidance

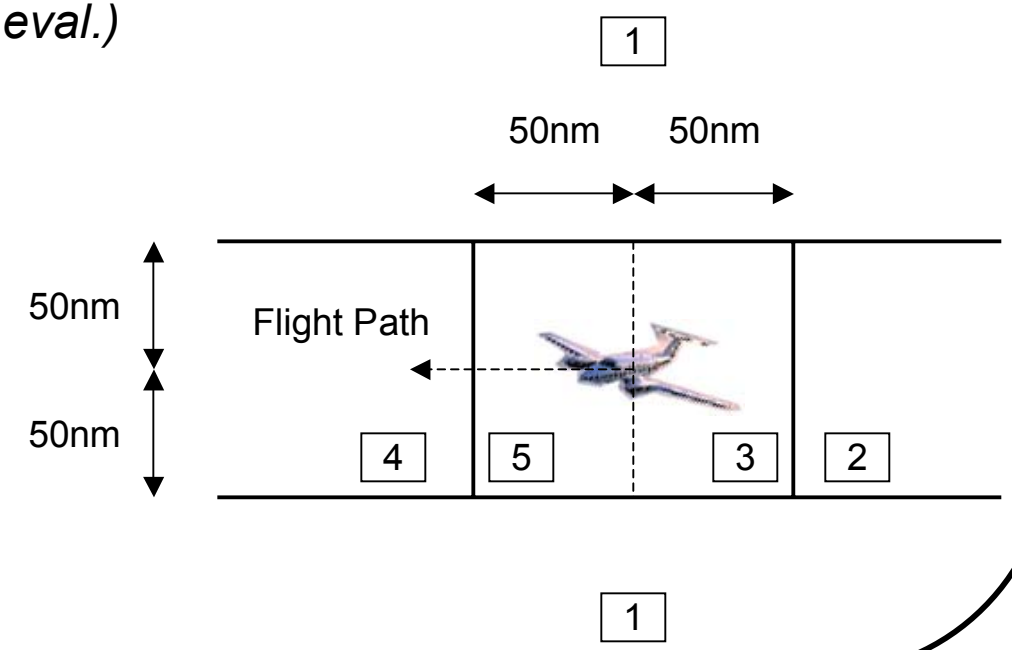
- Designing Utility (decision/SA-centered information)
- Designing Usability (min interpretation, heads-down)
- Design for appropriate use (T/S, age of the data…)

CoWS
Convective Weather Sources

Questions?

"Big Picture Weather SA"

- Structured evaluation of subjects' overall Wx SA
  - Based on their chart drawings of weather vs reference
  - Five chart regions considered (per drawing below)
    - » *Heavier weight in ranking for regions ahead of and near the aircraft*
  - Within each region, subjects evaluated on correct:
    - » *Location, orientation & shape of cells/lines/areas (60% of eval.)*
    - » *Cell directions & speeds (20% of eval.)*
    - » *Cell intensities (20% of eval.)*
  - Region evaluations:
    - » *Weighted (1 to 5)*
    - » *Summed*
    - » *Normalized to 1.0*



Characterizing Tactical/Strategic

Depends on your perspective: *(Dessouky, Kijowski, 1995)*

	Manufacturing	Flight Missions
Strategic	Batch Job	Mission with sortie
Tactical	Product	Mission phase
Operational	Operation/Task	Crew behavior

Aviation mission verb survey *(Schutte, 1997)*

Tactical: respond, act, react, do, fly, control, avoid, maneuver

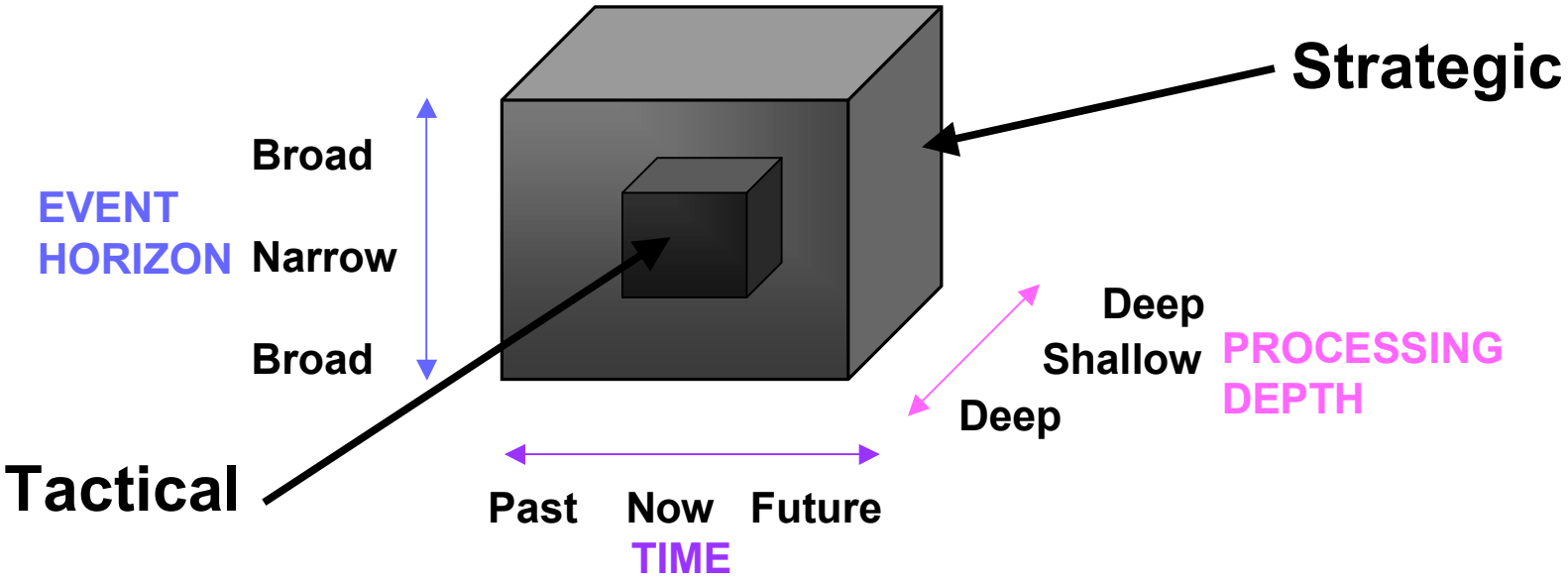
Strategic: plan, think, evaluate, anticipate, prioritize, decide, project.

Tactical / Strategic Models

Abstraction Hierarchy Model *(Moray, 1990)*

strategic
-- tactical
----action
-------neural events

Three-dimensional Model *(Rogers & Feyeresein, 1998)*



*** environmental uncertainty influences behavioral mode.*

Prior Findings

- Confidence in SA *(1)*
  - Both Window & Display better than Aural-only
- Information Sufficiency *(1)*
  - Display better than Aural only & Window
- Perceived Performance (NASA-TLX scale) *(1)*
  - Worst with Aural-only
- Cell Detection *(2)*
  - Display best (more Hits, fewer Misses & False Alarms)
- Range & Bearing Estimates *(2)*
  - Aural worst, Window best (display best for higher precision range)
- Big Picture SA *(2)*
  - Display best

(1) AvPsych 2001 (first 6 experimental subjects)
(2) DASC 2001 (6 subjects, 23 events)

Prior Findings

- Initially, appreciation of utility hides usability concerns

- Airplane Symbol / GPS Modes
  - Airplane symbol is very helpful,
  - Most switched modes (10/12),
  - All but 1 prefer GPS-Free

- Scale Usage
  - 50nm most preferred(largest with all contextual features)

- NEXRAD resolution
  - too coarse at small scales (5/10),
  - insufficiently precise to judge intensity gradient

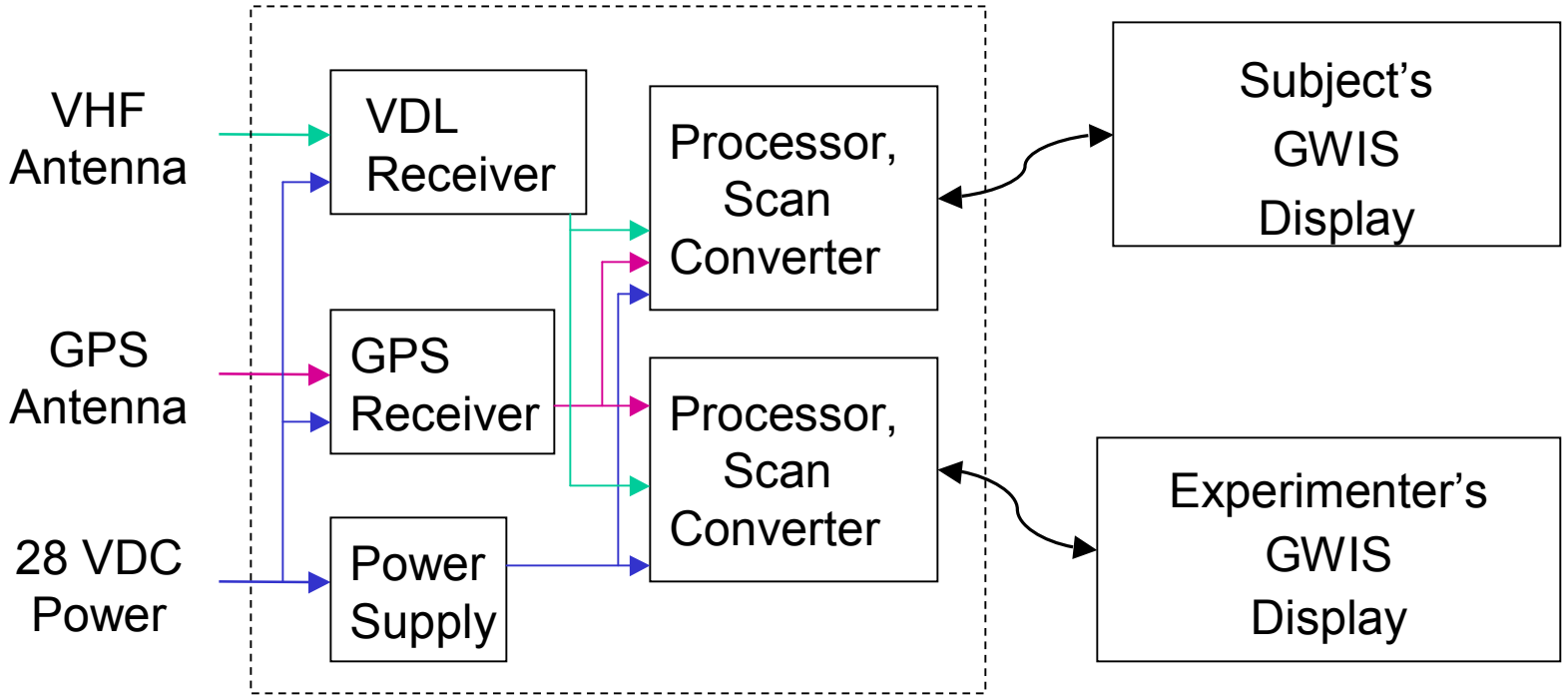
- Predictive information / tools required (8/12)

(3) SAE 2002 (12 experimental subjects)

The Future of CoWS

- Other Experimental Results
  - Full data set - Effects of cues on inflight SA & Decisions
    - » *proximity to convective frontal weather*
  - Effects of individual characteristics
    - » *personality, risk tolerance, weather knowledge*
  - Effects of weather graphics on preflight SA
- Usability Assessment of an available GWIS system
- Canned cues for subsequent comparative analysis
  - Onboard weather radar, GWIS radar mosaic,
  - Pilot observations, ground sources (ATC,FW, FSS),
  - HIWAS, video of external view.

Apparatus: GWIS Architecture



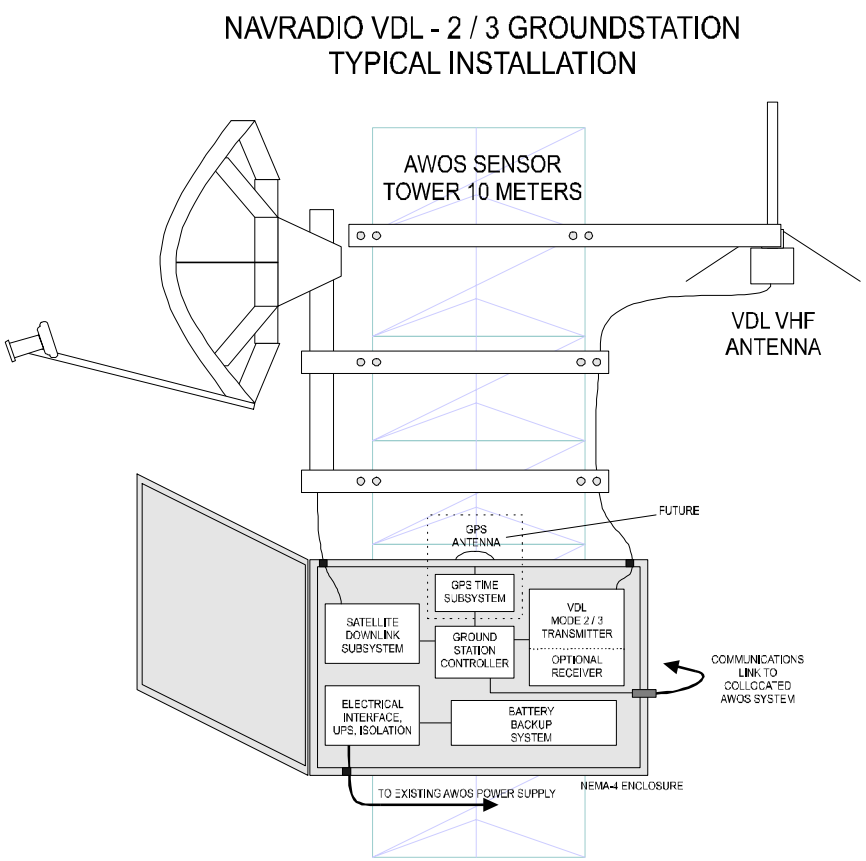
Antenna/Power Connections

Seat-Mounted Pallet

Tethered Displays

Apparatus: Ground Station

(Honeywell (NavRadio) AWIN CRA)



- Satcom antenna & receiver
- Processor & power supply
- VDL transmitter & antenna
- Ruggedized, Compact, Self-Contained

- 5 Receive/ Transmit Stations:
  LFI, PTB, DAN, CHO, HEF

- 1 AWIN Receiver/Processor at RTI/Hampton